STUDY OF THE EFFECTS OF RADIATION ON LITHIUM DOPED SOLAR CELLS

SEMI-ANNUAL REPORT

May 1970

CONTRACT NO. 952586

LOCKHEED-GEORGIA NUCLEAR LABORATORY

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Dawsonville, Georgia

NOTICE

This report contains information prepared by the Lockheed-Georgia Nuclear Laboratory under JPL subcontract. Its content is not necessarily endorsed by the Jet Propulsion Laboratory, California Institute of Technology, or the National Aeronautics and Space Administration.

NEW TECHNOLOGY

No new technology is reported.

ABSTRACT

This report describes facilities to be used in an experimental investigation of the effects of electron radiation on lithium p on n solar cells. The environmental chamber, data collection system, light source, electron source, temperature control system, and solar cell characteristics are discussed.

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SUMMARY

This report describes facilities specially designed and fabricated by Lockheed to be used in an experimental investigation of electron radiation effects on lithium p on n-type silicon solar cells. A total of 144 solar cells are to be tested in a simulated space environment. The solar cells are divided among four temperatures, -50°, 30°, 60°, and $80^{\circ}C$, to study the effects of temperature on radiation degradation. A ^{90}Sr-^{90}Y beta source adjusted to deliver approximately 1×10^{12} e/cm^2/day is used. The test will run continuously for 100 days with in-situ data collection at frequent intervals. I-V characteristics will be measured, and a computer will be used to derive the maximum power and various parameters of the solar-cell equation. The environmental chamber, temperature control system, beta source, light source, and data acquisition system are discussed in detail.

I - INTRODUCTION

The Lockheed-Georgia Nuclear Laboratory has designed and fabricated or procured special facilities to be used in an experimental investigation of electron radiation effects on lithium p on n-type silicon solar cells. This report describes facilities and procedures to be used in the performance of the test. Data derived during the performance of this test will be presented in a subsequent final report. Analysis of the data and conclusions formulated will also be given at that time. This method of reporting allows the reader to give his undivided attention to either the facilities and techniques used in performing the test or to the data and conclusions reached as a result of the test.

II - TEST MATRIX

The engineering test is shown in matrix form in Figure 1. The matrix elements were chosen in an effort to obtain maximum information from the experiment. Each element will provide significant information as a single-entity. In addition, each element bears a distinct relationship to one or more elements in the same row or column. To provide maximum utilization of the testing facilities, specimens have been eliminated from certain areas of the matrix. This has not affected the primary intent of the experiment, since test samples are provided at strategically located matrix elements so that the interrelationship between the different solar-cell materials and the space environmental parameters may still be deduced. However, it should be noted that some areas of correlation are dependent upon comparison of only one or two groups of samples. Where this is the case, large variations in damage to the two groups of samples are not anticipated. If unexpected variations are encountered, however, additional testing involving the affected matrix elements may be advocated for later experiments.

The test will yield information pertaining to the effects of temperature, illumination, and electron fluence on solar cells made from float zone and pulled silicon having either a low lithium concentration, a high lithium concentration, or no lithium (the standard cell). Selection of cells containing both a low lithium concentration and a high lithium concentration was prompted by explicit and implicit references in the literature related to lithium solar cells. Matrix elements showing any effects of the photo-emf (illumination) on radiation degradation are also included, since it is an established fact that the mobile lithium ion will drift in the direction of an electric field at a rate determined by the magnitude of the field. These drifted ions may have an effect on the compensation of damaged sites.

Examination of the matrix shows the information that can be deduced from the experiment. For example, five solar cells made from pulled silicon and having a high lithium concentration are irradiated while illuminated and held at 30°C. Data from this group of cells will be statistically compared to data obtained from the remaining five groups of cells in the 30°C, light column. This comparison will show the radiation degradation of the different groups of solar cells as influenced by a low and high lithium

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<tr><td colspan="3">Temperature</td><td colspan="4">-50°C</td><td colspan="4">30°C</td><td colspan="4">60°C</td><td colspan="4">80°C</td></tr>
<tr><td colspan="3">Solar Source</td><td colspan="2">Light</td><td colspan="2">Dark</td><td colspan="2">Light</td><td colspan="2">Dark</td><td colspan="2">Light</td><td colspan="2">Dark</td><td colspan="2">Light</td><td colspan="2">Dark</td></tr>
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All tests performed in vacuum of $< 10^{-6}$ torr.
Data taken in-situ at fluences of 10^{12}, 2×10^{12}, 5×10^{12}, 10^{13}, 2×10^{13}, 5×10^{13}, and 10^{14} e/cm^2.
Radiation rate of 10^{12} e/cm^2/day.

FIGURE 1 EXPERIMENT DESIGN MATRIX

concentration in float zone and pulled silicon, and will include a comparison to the standard n on p cell. In addition, data from this group of cells will be compared to data from identical groups of cells in each of the different temperature columns. This comparison will show the temperature dependence of radiation damage. Finally, the data will be compared to data taken from an identical group of cells at 30°C under no-light conditions to give insight into the photo-emf effect on radiation degradation. Tracing of this particular group of cells through the matrix demonstrates the various interrelationships and shows the broad range of information to be gained as a result of this experiment.

III - ENVIRONMENTAL CHAMBER

An environmental chamber was specially designed and fabricated for the performance of this irradiation test. The chamber is stainless steel with facilities for four heat sinks, a ^{90}Sr Beta source, and a Corning Code 7940 fused silica window to provide access for the 13-inch-diameter light beam from a spectrolab Model X-25/9613L solar simulator. The primary criteria in the design of the environmental chamber were cleanliness (minimization of hydrocarbon contamination) and the ability to maintain and control the pressure in the range of 10^{-6} to 10^{-7} Torr.

The top assembly drawing of the environmental chamber is shown in Figure 2. The chamber may be divided into three separate sections. In the center is the main body of the chamber, which contains the test specimens, a vacuum gauge, and the fused silica window. To the right of the main body is the source-handling and storage area. The cross-hatched area is a cast lead shield. When it is necessary to enter the room during the test, the ^{90}Sr source is stored within this lead-shielded area, and the radiation dose rate is reduced to acceptable levels. The lead shield is cast in sections so that it is easily removable. Push rods or source operators extend through the lead shield and are magnetically coupled to the ^{90}Sr source plaques mounted on guides inside the chamber.

To the left of the main body is the vacuum pumping station, which consists of two ion pumps, one titanium sublimation pump, and three vacsorb pumps. The smaller ion pump has a maximum pumping speed of 25 liters/second. A 550 liter/second titanium sublimation pump is an integral part of the smaller ion pump. The larger ion pump has a maximum pumping speed of 125 liters/second and is of the straight-through type (i.e., there are flanged outlets on each side of the pump). The three vacsorb pumps are connected to the main body of the chamber through this pump. The vacsorb pumps are individually valved into a cross-section which may be valved-off from the main part of the system once the rough-down is accomplished.

Pressure control is accomplished by cycling the larger ion pump on and off. The smaller ion pump operates continuously and serves as a pressure controller. Control is accomplished as follows. Both ion pumps are turned on, and the base pressure of the

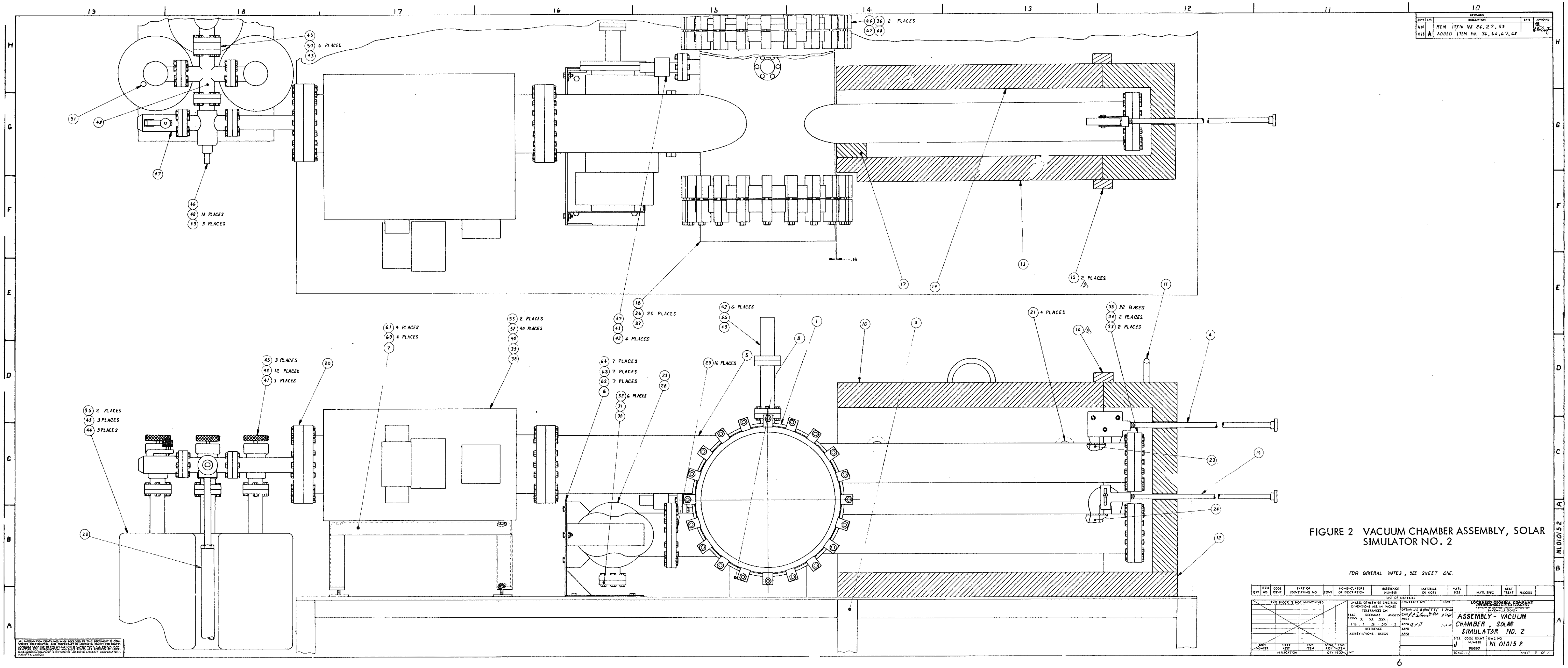


FIGURE 2 VACUUM CHAMBER ASSEMBLY, SOLAR SIMULATOR NO. 2

chamber is obtained (approximately 1×10^{-8} Torr). A variable leak is then adjusted to admit dry nitrogen to the chamber until an equilibrium pressure of 5×10^{-7} Torr is obtained. The power supply current of the small ion pump drives an L & N recorder equipped with cam-operated microswitches which turn the large ion pump on and off. At a pressure of 5×10^{-7} Torr, the large ion pump is turned off, and the chamber pressure begins to rise at a rate determined by the variable leak valve. At a pressure of approximately 9×10^{-7} Torr, the large ion pump is turned on, and the pressure drops to 5×10^{-7} Torr. The cycling rate is adjusted by changing the rate of admission of dry nitrogen through the variable leak valve.

Chamber cleanliness was obtained for the most part by carefully designed and executed cleaning procedures carried out during fabrication of individual assemblies and assembly of the complete chamber. All surfaces were glass-shot-peended and then solvent-cleaned. Weldments were acid-cleaned prior to the solvent wash. The various parts of the chamber were bolted together using OFHC copper seals. One viton O-ring was required to seal the fused silica window to the chamber. The completely assembled chamber was pumped down and baked out at approximately 100°C to obtain the final cleanup. The duration of the bake-out was approximately 40 hours, and a base pressure less than 1×10^{-7} Torr at temperature was obtained. (Test solar cells were not in the chamber during bake-out.)

After completion of the bakeout and return of the chamber to room temperature, the pressure dropped to 6×10^{-9} Torr. The vacuum pumps were turned off, and the chamber was vented to dry nitrogen. The test item flange was removed, and the solar cells were mounted on the major heat sink assemblies.

IV - TEST ITEM FLANGE

The test item flange is a critical component of the environmental chamber and was handled as a separate and distinct design effort. Figure 3 shows a top assembly view of the test item flange. The major and minor heat sinks, the light shield assembly, the hermetic feedthroughs, and the layout of the solar cells as viewed from the light source end of the chamber are shown.

The major heat sinks are massive copper bars vacuum oven-brazed into a 1/4-inch-thick stainless-steel plate. The temperature of these copper bars is controlled and monitored. Looking from left to right in the side view or from top to bottom in the top view, we see the 28 solar cells which will be controlled at 80°C, 54 solar cells at 60°C, 44 cells at 30°C, and 18 solar cells at -50°C. Five-watt power resistors are uniformly mounted along the air side of each of the 80°, 60°, and 30° sinks. The -50° sink is used as the evaporator of a two-stage mechanical refrigeration system. The major path for heat flow is from the 80° sink toward the -50° sink, where any required heat removal is accomplished. The temperature control system for the 30°, 60°, and 80° sinks is relatively simple. To illustrate, eleven 5-watt resistors are thermally attached to the back of the 60° heat-sink bar. There are three significant sources of heat input to this bar and one output. These three inputs are (1) from the light source, (2) from the 80° sink, and (3) from the power resistors. The one output is the heat transfer to the 30°C sink. Radiation losses are negligible. The temperature of the sink is controlled by the on-off action of the power resistors. The power resistors are connected in parallel, with one side connected through a pair of microswitches mounted on an expanded-range L&N recorder to a Variac. The L&N recorder is driven by thermocouples mounted on the air side of the 60° sink. Cam action within the recorder then turns the power on or off as required. The frequency or period of operation of the temperature-limiting microswitches can be adjusted by decreasing or increasing the voltage setting of the Variac.

As stated above, the -50°C heat sink is used as the evaporator of a two-stage mechanical refrigeration system. This system was custom designed and fabricated with new components to minimize the possibility of failure during the test. Compressed Freon 502

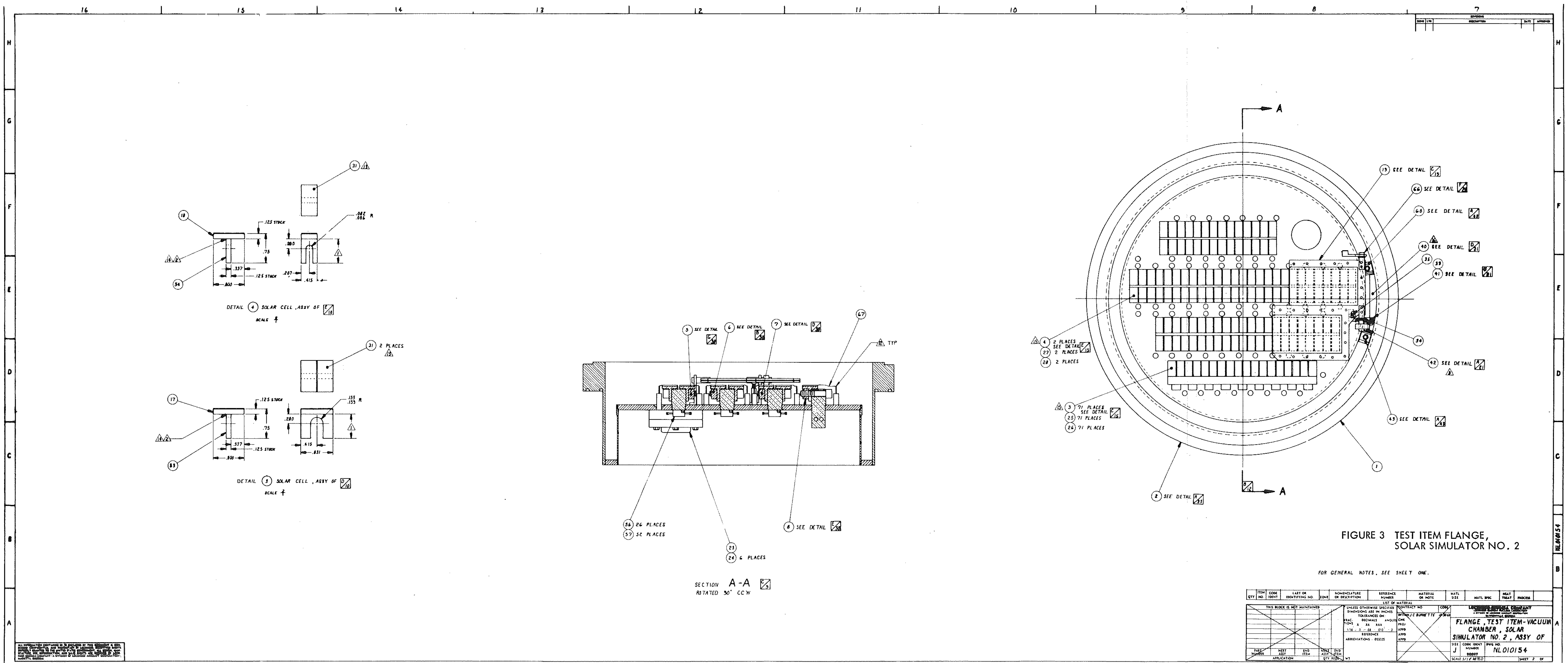


FIGURE 3 TEST ITEM FLANGE, SOLAR SIMULATOR NO. 2

refrigerant leaves the compressor and flows to the condenser. The condenser is cooled to $-9^{o}C$ by a separate package refrigeration system. Refrigerant leaves the condenser at $-9^{o}C$ and flows through cooled lines to an expansion valve located behind the $-50^{o}C$ sink. Refrigerant is injected through the expansion valve into the evaporator ($-50^{o}C$ heat sink), where it boils and removes heat. A thermostatic sensor in the refrigerant return line causes the expansion valve to maintain liquid refrigerant in the evaporator and return line up to the location of the sensor. A unique feature of this two-stage refrigeration system is that the package refrigeration system used to cool the primary system condenser and liquid lines serves as a backup in the event of primary compressor failure.

Control of the $-50^{o}C$ heat sink is accomplished by a thermocouple-driven L&N recorder which turns on and off a 10-watt heater on the evaporator side of the primary system expansion valve. This heater causes the sensor in the refrigerant return line to operate and changes the volume of freon metered through the expansion valve.

The minor heat-sink assemblies and solar-cell mounting pads are shown at the left of Figure 3. These are simply 1/8-inch-thick copper T sections. The top of the T is just large enough to accommodate two solar cells. The pre-tinned solar cells are positioned on top of these pre-tinned T sections, and heat is applied. The re-flow solder process was performed in an inert atmosphere, and a total heat time cycle of approximately 5 minutes was required. These T sections are then securely bolted to the major heat sink assemblies, and the power lead is attached.

As indicated earlier, some of the solar cells will be irradiated while in the dark. The shield which allows this to be accomplished is shown in the right-hand side of Figure 3. The shield is 5-mil aluminum foil stretched between a stainless steel framework and is magnetically operated from outside the chamber.

A viewport has also been provided on this test item flange. The solar cell is mounted to this viewport and provides an additional means for checking the light source.

V - ^{90}SR-^{90}Y SOURCE

The source/solar cell geometry required to deliver the desired flux (10^{12} e/cm^2/day) has been determined. The source is composed of two groups of five stainless-steel tubes oriented so as to deliver a flat flux distribution to the plane of the solar cells. Each 0.010 wall stainless-steel tube has an active length of 20 inches and contains 10 curies of Sr activity.

An experimental procedure was used to develop the source/solar cell geometry. This procedure yielded the electron flux and energy spectrum. Ten source tubes were used that are identical to those which will be used in the radiation test but containing much less activity. Each of these tubes contains 13 microcuries of ^{90}Sr. An anthracene detector and multichannel analyzer (MCA) were used to make flux and spectral measurements on these diluted source tubes. System calibration was performed using a weak ^{60}Co source.

The primary method of energy deposition in the scintillation detector under consideration is by single Compton scatter. The Compton process is the dominant method of interaction between gamma rays and organic scintillators in the energy range of 20 eV to 30 MeV. The total energy of the incoming photon may be deposited in the scintillator only after multiple Compton scatters terminating in photoelectric absorption. Since the dimensions of the anthracene detector (1.5-inch diameter x 1-inch thick) are too small to allow for the multiple scatter process, the response of the detector to the ^{60}Co source is quite similar to the response to the ^{90}Sr source.

An expression for the degraded photon arising from a Compton collision is:

$$E_2 = \frac{E_1}{1 + \frac{E_1}{mc^2}(1 - \cos\varphi)}$$

where E_1 and E_2 represent the energy of the incident and scattered photons, respectively. Setting φ equal to 180° and subtracting E_2 from E_1 yields the familiar expression for the kinetic energy of the Compton electron:

$$E_c = \frac{E_1}{1 + \frac{.51}{2E_1}}$$

In the case of ^{60}Co, where there are two primary photons, the value for E_c is based on the average photon energy (1.25 MeV). Setting E_1 equal to 1.25 MeV, we find E_2 equals 0.21 MeV, and E_c equals 1.04 MeV. The peak of the Compton distribution collected by the 512-channel MCA will be at 1.04 MeV. This spectrum is shown in Figure 4. Spectral and flux measurements of the ^{90}Sr-^{90}Y source were made after the calibration procedures were completed. Figure 5 shows the beta spectrum. The electron flux emitted by the diluted source tubes was determined by a simple arithmetic summation of the counts under the curve. The flux obtained from the full-strength source tubes was determined by a linear extrapolation technique that has been used in previous tests incorporating the Sr source. The extrapolated results agreed within one percent with vacuum Farrady Cup measurements.

Spectral measurements were made with the source and detector in a minimum scatter geometry, and then the source and detector were placed inside a heavy walled aluminum tube to simulate the scatter geometry of the actual test. No significant spectral change was observed.

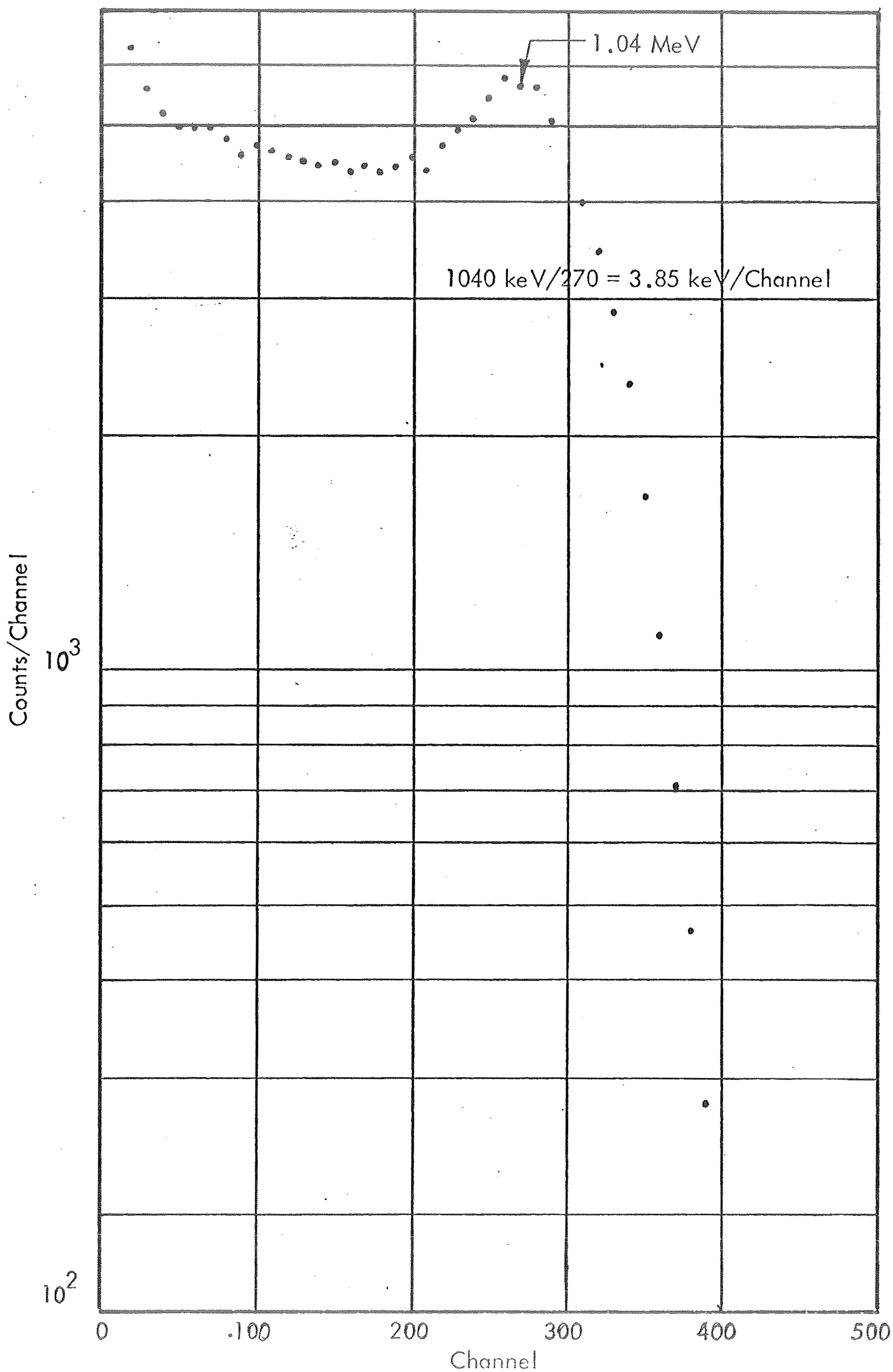


FIGURE 4 COMPTON SPECTRUM OF ^{60}Co

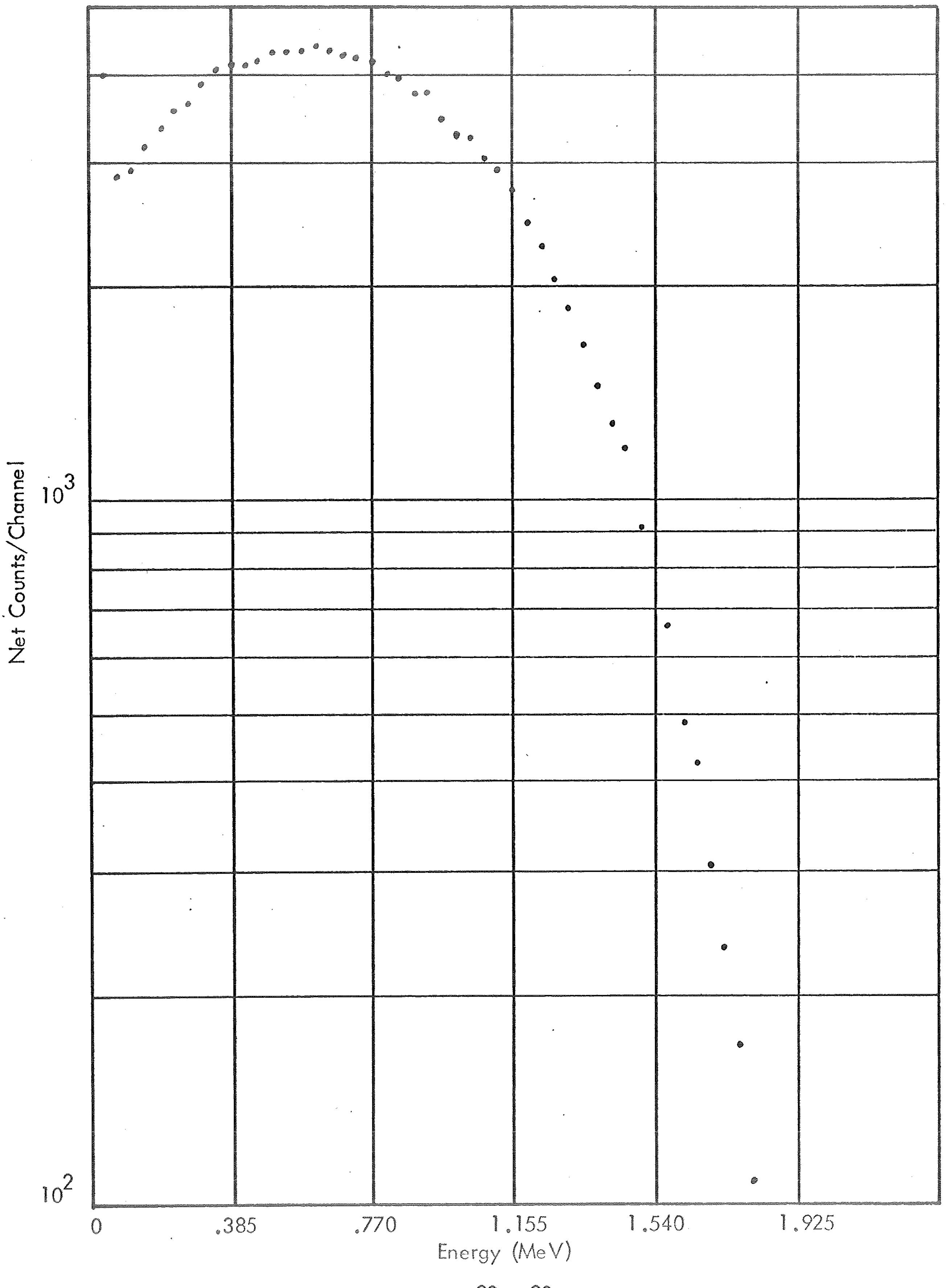


FIGURE 5 ^{90}Sr–^{90}Y SPECTRUM

VI - SOLAR SIMULATION (LIGHT)

One requirement of the radiation effects test is that solar cells be fully illuminated for the entire duration of the test. Two separate illumination systems are used. A Spectrolab X-25/9613L is used exclusively for data collection, and a Xenotech Model XE-20 is used to provide illumination for the long time periods between data collection cycles. This dual illumination system is used to circumvent possible maintenance problems and expenses which may be incurred as a result of operating the X-25 for long time periods.

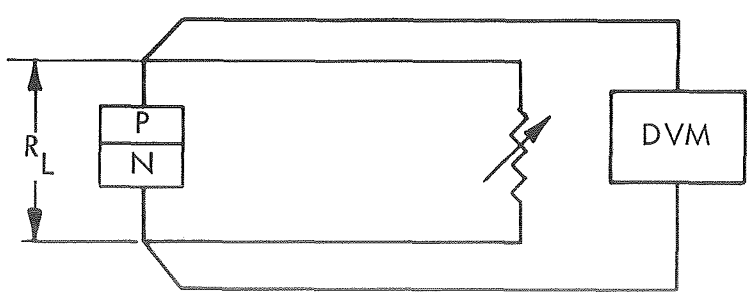
The X-25 is calibrated using a thermopile and a photovoltaic standard cell supplied by the Jet Propulsion Laboratory. The standard cell and thermopile are positioned at the end of the environmental chamber and in the same plane occupied by the test cells when they are in position in the chamber. Light from the X-25 is projected through the fused silica window onto these detectors. The light intensity is then adjusted to give the correct standard cell output corresponding to 140 mw/cm^2. The output of the standard cell and thermopile are recorded. The red/blue ratio using Coming filters Blue 1-57 and Red 7-69 is then measured and recorded. The standard cell and thermopile are then positioned in front of and centered on the fuxed silica window. Measured values are again recorded. These front-of-the-window measurements will be used for calibration of the light source prior to each data-collection cycle. The XE-20 will be calibrated in a similar manner.

As indicated earlier, a viewport was installed in the test item flange. A solar cell will be positioned behind this window to provide a readily available measurement of light intensity. Correlation of measurements from this cell and the standard cell placed in front of the fused silica window will provide assurance that the transmission characteristics of the window have not changed.

VII - DATA COLLECTION

A semi-automatic data acquisition system (shown in block-diagram form in Figure 6) is used to measure the I-V characteristics of the test cells. The data collection system operates as follows: The first load resistor is manually switched across the load leads. The automatic portion of the system is then activated. The first solar cell is switched into the load leads, and the voltage drop across the load resistor is measured by a digital voltmeter. The sample number and digital voltmeter reading are then recorded on punched paper tape and standard typewritten format. The automatic system indexes to the next solar cell, and the new sample number and voltmeter reading are recorded. Solar cells are automatically indexed into the measurement system until all information for this one load point is recorded. The next load resistor is manually switched into the measurement system, and the sequence is repeated. This process is repeated until a total of 15 load resistors spanning the solar-cell characteristic have been switched into the system. Approximately 150 minutes are required to collect an entire data set. The paper-tape data record is then transferred to cards in the proper format and is computer-processed.

The current corresponding to the voltage drop across each load resistor is computer-calculated. Each load resistor position is calibrated to obtain an accurate current value. The load resistance includes the resistance of the leads between the solar cell and the load-resistor decade box. Voltage measurements are made directly across the solar cell. The measurement circuit for an individual solar cell is illustrated below.



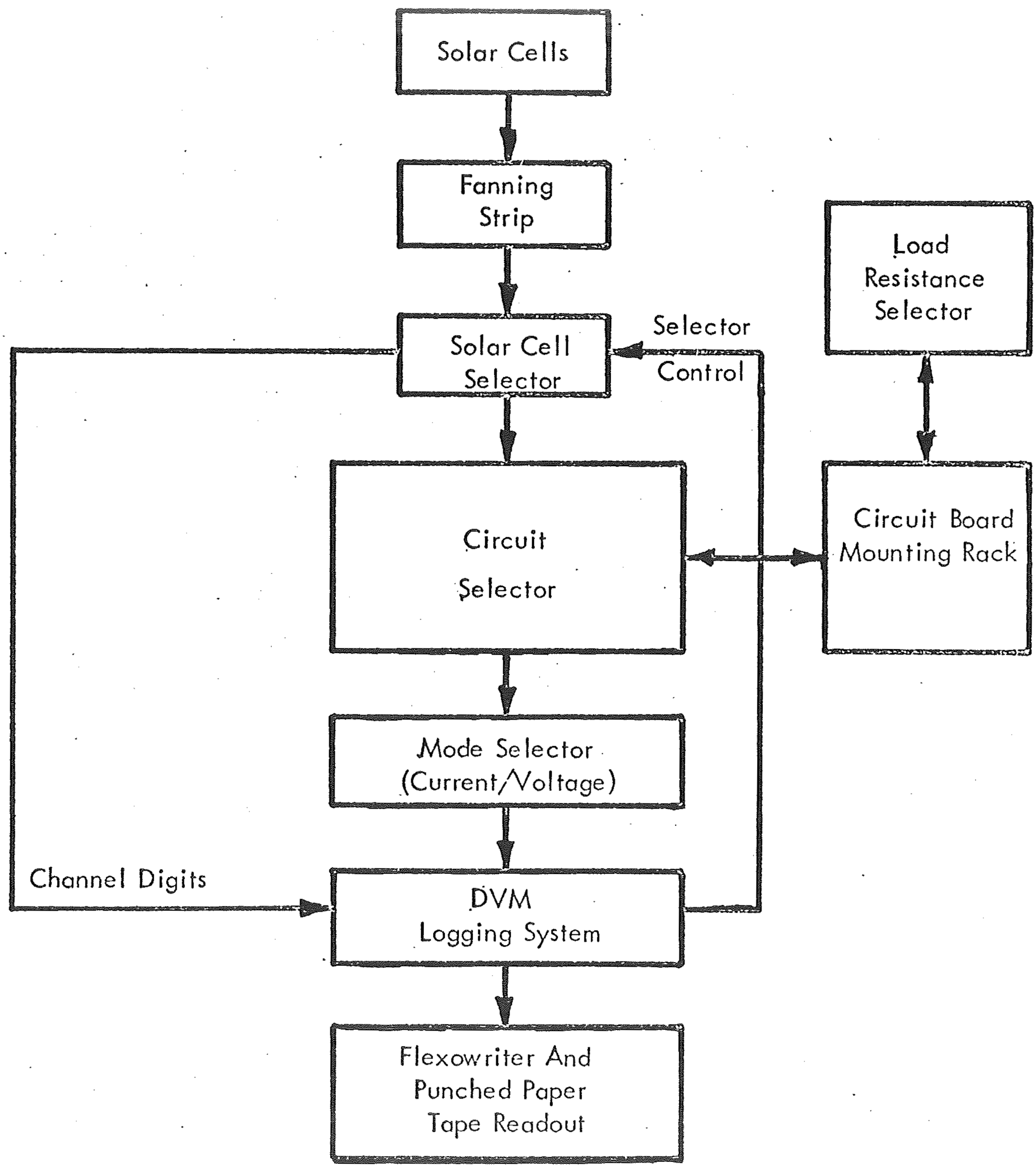


FIGURE 6 INSTRUMENTATION DATA COLLECTION SYSTEM

Data put into the computer will be sorted, and the current corresponding to each data point will be calculated. The computer will then take the 15 current-voltage pairs for each solar cell and fit them to the solar-cell equation using a least-squares routine. The four unknown parameters of the solar-cell equation, Ig, Io, Rs, and n, will be determined. The maximum power point will then be calculated. The computer will then take all 75 current-voltage pairs associated with each matrix element (assuming five similar solar cells per matrix element) and will fit these points to the solar cell equation. An average maximum power for the entire group will then be calculated. This calculated value will provide a very useful tool for comparison of data among the various matrix elements.

The computer output will include the solar-cell identification, fluence, 15 current-voltage pairs, maximum power value and corresponding current-voltage point, the RMS error associated with the maximum power computation, the parameters Ig, Io, Rs, n, and the average maximum power for each matrix element.

Before any valid conclusions can be drawn from test results, it is necessary to determine whether differences in parameter values between groups of specimens are significant or due purely to chance. The application of certain statistical techniques to the test results obtained will accomplish such determination.

First, the parameter values obtained from each group of specimens will be tested for "goodness" of fit to normal and log-normal distributions. This will be done graphically, using probability paper for each of the two distributions. Visual examination of the graphs will reveal which of the two distributions should be assumed for further statistical manipulations.

The following discussion deals with the assumption that a normal distribution of parameter values has been determined. However, it applies equally well to a log-normal distribution if logarithmics of parameter values are used in the calculations instead of parameter values.

Group means and standard deviations will be calculated, and each speciment parameter value will be tested to see that it lies within plus or minus three standard deviations of its group mean. The specimens whose parameters fall outside the prescribed limits will be designated "unusual" specimens, and data from them will be omitted from further statistical calculations.

New group means and standard deviations will be calculated, omitting the "unusual" specimens, and each remaining specimen parameter will be tested to see that it lies within plus or minus three standard deviations (new) of its group mean (new). Those specimens whose parameters fall outside the new limits will be designated "unusual" specimens and will be omitted from further statistical consideration.

The process will be repeated until no additional "unusual" specimens appear.

Final group means and variances remaining after all "unusual" specimens have been identified and eliminated will be used to compare the groups, one with the other, for significant differences by means of the tests described below.

Significance of the Difference Between Two Group Means

To make this test, a null hypothesis is set up that the two group means, $\overline{X}_1$ and $\overline{X}_2$, are from the same population in regard to $\overline{X}_p$, the population mean. This hypothesis is tested by determining the probability of t, where t is the ratio of $\overline{X}_1 - \overline{X}_2$ to an estimate of the standard error of the difference between the two group means.

The standard error of the difference between two group means, $\overline{X}_1 - \overline{X}_2$, is given by

$$\sigma_{\overline{X}_1-\overline{X}_2} = \sigma \sqrt{\frac{1}{N_1} + \frac{1}{N_2}}$$

where σ is the standard deviation of the population, and

N_1 and N_2 are the numbers of specimens in the two groups, respectively.

This expression cannot be used because the value of σ is not known. Consequently, the following estimate of the value of σ is made from the information given by the two groups:

$$\hat{\sigma}_{1+2} = \sqrt{\frac{\sum x_1^2 + \sum x_2^2}{N_1 - 1 + N_2 - 1}}$$

where $\sum x_i^2$ is the summation of the squares of the deviations of each specimen's parameter value in the ith group from the group mean.

The estimated standard error of the difference between the two group means can now be computed:

$$\hat{\sigma}_{\overline{X}_1 - \overline{X}_2} = \hat{\sigma}_{1+2} \sqrt{\frac{1}{N_1} + \frac{1}{N_2}}$$

Finally, the desired significance ratio, t, is obtained:

$$t = \frac{\overline{X}_1 - \overline{X}_2}{\hat{\sigma}_{\overline{X}_1 - \overline{X}_2}}$$

Values of t for given degrees of freedom, n, and at specified levels of significance (P) can be found in most statistics textbooks or handbooks.

For this test, $n = N_1 - 1 + N_2 - 1$, since one degree of freedom was lost when $\sum x_1^2$ was computed about $\overline{X}_1$, and another degree of freedom was lost when $\sum x_2^2$ was computed about $\overline{X}_2$.

A level of significance (P) of 0.05 will be used. This means that in only 5% of the test cases will the test indicate a significant difference when actually none exists. Such an occurrence is called a Type I error. If the hypothesis that the two groups are from the same population is false, the test will indicate no significant difference some percentage of the time. Such errors are called Type II errors. It is impossible to say what the percentage will be, because it will not be known how false the hypothesis is. However, the percentage will be smaller for $P = 0.05$ than if $P < 0.05$, and it will get smaller as P increases.

If the above-described test results in a conclusion that no significant difference exists between the two groups, they will be further tested as to the differences between their variances.

Significance of the Difference Between Two Group Variances

When $\hat{\sigma}_1^2$ and $\hat{\sigma}_2^2$ are independent estimates of σ^2 from the same normal population, their ratio, $\hat{\sigma}_1^2 / \hat{\sigma}_2^2$ is distributed according to the F distribution with $n_1 = N_1 - 1$ and $n_2 = N_2 - 1$ degrees of freedom. Tables of F values for given degrees of freedom at selected probabilities can be found in most statistics textbooks and handbooks.

For this test, the P (probability) = 0.05 level will be used as the criterion to test the hypothesis that the two groups are from the same population in respect to σ^2.

Estimates of the group variances, $\hat{\sigma}_1^2$ and $\hat{\sigma}_2^2$ will be found thus:

$$\hat{\sigma}_i^2 = \frac{\sum x_i^2}{N_i - 1}$$

and the ratio will be

$$F = \frac{\hat{\sigma}_1^2}{\hat{\sigma}_2^2}$$

<u>Selection of Probability Criteria</u>

For practical purposes, the probability which is to serve as the criterion of significance should be chosen in the light of the type of error which should be avoided. If Type I errors should be as few as possible, P should be very small. If Type II errors should be few, P should be large.

When solar cells are used in space applications where replacement or repair of defective cells is impossible, and where huge sums of money are wasted if the equipment does not operate optimumly, it is imperative that the solar cells to be used be meticulously selected. If a Type I error is made in drawing conclusions from test data, money and time might be uselessly spent in procuring sophisticated types of cells and in providing specific environmental conditions for their use. If a Type II error is made, less than optimum performance would be obtained from the resulting equipment.

A significance level of P = 0.05 has been selected as a compromise value which will provide a 95% chance of avoiding Type I errors and some unknown (but greater than that if P were selected less than 0.05) chance of avoiding Type II errors.

To establish the validity of the null hypothesis necessary to perform the t and F tests, it is proposed that parameter measurements be made on all groups of specimens (as shown in the matrix) under identical environmental conditions prior to the start of the experiment. These data would be used to compare all groups of similar specimens, one with each of the others using the t and F tests. Such comparison will allow a determination to be made as to whether the groups can be considered, at the 0.05 significance level, to have been drawn from the same population. If the determination is "negative" for any type of specimens, then the significance level will be lowered sufficiently to make the determination "affirmative" for all types of specimens. The new lowered significance level will then be used for any subsequent analyses of experimental data.

Determination of Group Size

For making the significance tests described above, it is not necessary that all groups contain the same number of specimens. However, since the tabulated values of F vary with n_1 as well as with n_2, selection of a minimum group size is simpler if it is assumed that groups will have the same number of specimens. To do this, tabulate t and F versus degrees of freedom at P = 0.05 (if groups are same size, n = 2N - 2 for both t and F).

Degrees of Freedom (n)	t	F
2	4.303	161.450
4	2.776	19.000
6	2.447	9.277
8	2.306	6.388
10	2.228	5.050
12	2.179	4.284

In this tabulation it is evident that t does not vary much for degrees of freedom greater than 4, whereas F has considerable variation until n = 8. It thus appears that minimum group size should be no less than three and preferably should be at least five (since group size = (n + 2)/2.

VIII - SOLAR CELLS

Specifications of the solar cells used in the irradiation test are shown in Table I. Items 1, 3, and 6 have a low lithium concentration, while Items 2, 4, 5, and 7 have a high lithium concentration.

TABLE I

ITEM NO.:	1	2,5	3,6	4,7	3
Silicon Growth Method	FZR	FZR	CG	CG	CG
Ingot No.	202-8	202-8	1657	1729	--
Manufacturer	Monsanto	Monsanto	Centralab	Centralab	Centralab
Resistivity (ohm-cm)	~ 70	~ 70	~ 20	~ 40	~ 10
Dopant	Phosphorus	Phosphorus	Arsenic	Arsenic	Boron
Orientation	111	111	111	111	Mixed
Lithium Diffusion	425°C - 90 min. (+120 min. redist.)	425°C - 90 min.	425°C - 90 min. (+120 min. redist.)	425°C - 90 min.	--

Lithium Source: Lithium aluminum hydride in ether, paint-on.

BCl_3 Diffusion: 1050°C 8-5-8*

*The three times are in minutes and are in the following order:

Preheat-BCl_3 Tack-on-Diffusion.